Anthropogenic Waste Management Using Material Flow Analysis Under Data Limited Conditions in Mandalay, Myanmar(Abstract_要旨)

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論文題目	Anthropogenic Waste Management Using Material Flow Analysis Under Data Limited Conditions in Mandalay, Myanmar（ミャンマー・マンダレーにおけるデータ制約下でのマテリアルフロー解析を用いた人由来廃棄物の管理）		

（論文内容の要旨）

This study aims to quantity the anthropogenic organic wastes from an urban city by using material flow analysis (MFA) under data limited conditions as a case study in Mandalay, Myanmar, and to propose an improvement measure to anthropogenic organic wastes pollution, focusing on fecal sludge collection business, which is one of major challenges in organic waste management in the city based on the results of MFA.

Chapter 1 introduced the background of the study that motivates to conduct this research and described the objectives of the study, research framework and schedule of the survey.

Chapter 2 aimed to review the current constraints on the fecal sludge collection businesses of the developing countries, and possible solutions and lesson learned from different countries along with innovative sanitation technologies recently developed. Fecal sludge collection business is one of the major organic waste management challenges in Asian and Africa countries.

Chapter 3 purposed to quantify the organic waste pollution load from the urban Mandalay. A mass flow model was developed on nitrogen and phosphorus, focusing on organic wastes. The components included in the system were Agriculture, Livestock, Industry, Household and Onsite sanitation system, while the system boundary was five urban townships with 1.2 million populations of Mandalay city. In addition to the secondary data collection on basic statistics, 400 household surveys, and interviews to 10 farmers, 21 livestock owners and 65 industry managers were conducted to develop the model. Results showed that the total anthropogenic organic waste pollution load was 5821 ton-N/year and 776 ton-P/year from the urban city. Onsite sanitation wastes (toilet discharge and fecal sludge) was the heaviest waste loading flow out of the five model components, accounting 54% for N and 53% for P of total pollution load to the environment, while Household waste represented as 35% of N and 33% of P, and Industrial sector contributed to 8% of N and 10% of P. Livestock sectors played an important role of resource recovery, receiving 10% of N and 5% of P from households, industries, markets and agricultural sector as organic wastes. Agricultural activity of recycling and resource recovery was not active in this area. Applying nutrients from animal manure, fecal sludge, and organic solid waste in the agricultural sector can reduce the pollution load to the environment, and reduce the chemical fertilizer demand in the city. Onsite sanitation management was needed to take action urgently in this study area.

Chapter 4 proposed and validated a method to simplify MFA by using secondary data and expert judgement to overcome the time and labor consuming challenges of conventional MFA development. We developed a simplified MFM (sMFA) in stochastic manners by Monte Carlo simulation, and compared it with a conventional MFA with intensive data collection (iMFA) that was made in Chapter 3. For sMFA, 10 experts from related fields were interviewed for the unavailable data from secondary review. Two models were

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compared by median-based and range-based variability analysis to examine the uncertainty. The impacts of each parameter to the total pollution load by changing the value of parameter from 50 percentiles to 10 and 90 percentiles were examined. Results estimated that the total organic pollution load with iMFA and sMFA accounted as 4,282-5,080-6,069 N-ton/year (1st, 2nd and 3rd quantiles) and 4,967-5,846-6,918 N-ton/year, and the total phosphorus discharge to the environment as 806-1,002-1,267 P-ton/year and 1,024-1,232-1,507 P-ton/year. The median based variability suggested the possibility of sMFA to be used as an alternative of iMFA for overall waste loading to the environment, and for most of individual flows to the environment except fecal sludge and industrial waste. As expected, sMFA showed the wider range than iMFA in many parameters estimation. Proportion of toilet wastes discharged to the environment, industrial wastewater amount, and N/P loading in human excreta and greywater were ranked as the biggest sensitive parameters to the total pollution load to the environment. Therefore, essential data collection for industrial sectors and for illegal waste discharge would be required to reduce the uncertainty. For the best options, the integrated application of sMFA and iMFA with collection of essential and sensitive parameters was recommended.

Chapter 5 investigated that the reasons for selection of informal emptying businesses and pointed out the recommended measures for reducing the lost revenue for FPs (Formal emptying service providers) by informal businesses, because the previous chapter suggested onsite sanitation and fecal sludge management were essential to improve the waste management of the study area. Ninety-one (91.0) % of households out of 400 interviewed households recognized FPs only. Among 134 emptying-experienced households, 92.5% selected FPs but 64.5% requested services through illegal means. These service fees did not become revenue for FPs; this was a major informal emptying business in the city. It was estimated that FPs lost 76.5% of the theoretical maximum revenue due to informal business. Logistic regression analysis indicated people's intention to shorten the waiting time through illegal contact, even by paying a higher fee. This is supported by a significantly higher willingness to pay for shorter waiting times (p<0.001) and faster contact methods (p<0.001). As emptying services are usually required immediately after fecal sludge is over-accumulated, shorter waiting time and faster contact method were preferred to select the informal business. This indicates that if FPs make their procedure less bureaucratic and more customer friendly, they could reduce revenue loss, charge more, and increase profits.

Chapter 6 represented the summary of the thesis and recommendations for the further studies such as development of quick and convenient technologies for the monitoring of industrial waste quality and quantity, the development of fecal sludge collection system with demand creation, safe operation, transportation and disposal as well as safe money transfer system.

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（論文審査の結果の要旨）

本研究は，ミャンマー国の第二の都市であるマンダレー市を事例とし，多くの途上国で劣悪な管理状態にある人由来廃棄物の適正管理を主目的とし，窒素およびリンの都市マテリアルフローを明らかにするとともに，特にオンサイト衛生施設由来のし尿汚泥の不法汲取の選好要因解明と適正化策の提案を行ったものである。そのため，マンダレーにおいて，400 一般世帯，10 農家，21 畜産家，65 工場でインタビュー，10 名の行政等の専門家へのヒアリングを実施し，同地域でのマテリアルフローを求め，下記に示す種々の成果を得た。

(1) マンダレーの都市部を対象とし，有機系廃棄物・排水に注目して 10 要素および 24 プロセスより構成される窒素・リンのマテリアルフローモデルを構築した。一般世帯等への訪問インタビュー調査による一次データの収集を行い，これをモデルに適用した。その結果，環境への負荷は 5,821 ton-N/year および 776 ton-P/year と推計され，中でもオンサイト衛生施設からの放流水・浸透水が窒素・リンともに最も大きなフローであった。資源利用の観点からは，廃棄物由来の資源を現状で受け入れている畜産の役割が大きいことが示された。
(2) データの制約が大きい環境下でも適用可能な簡易化マテリアルフローモデルを考案した。マンダレー都市部を対象に既存および簡易化マテリアルフローモデルを確率論的に解析し，妥当性を検討した。既存および簡易化モデルでの環境への窒素負荷は，それぞれ 4,282-5,080 - 6,069 N-ton/年および 4,967-5,846-6,918 N-ton/年（第 1，2，3 分位点）であった。リンについても両モデルは大きな乖離のない結果となり，簡易化モデルはデータ制約下でのマテリアルフロー解析を実現するための代替モデルとなりうることを示した。
(3)適正なし尿汚泥の汲取によるオンサイト衛生施設の運用改善を目指し，し尿汚泥の不法汲取の発生理由と対策を検討するため，400 世帯への訪問調査の結果から不法汲取が住民に選好される要因を解析した。その結果，92.5%の汲取は正規業者によるものの，その 64.5%は違法な手続きによる不法汲取であった。不法汲取により正規業者の損失は潜在的収入の 76.5%に達することを推計した。不法汲取の待ち時間は正規汲取よりも有意に短く（$p < 0.05$），住民はより利便性の高い手続き($p < 0.01$)，待ち時間の短縮($p < 0.01$)への有意な支払い意思を有していた。正規業者の手続きを改善し，利便性の高いサービスとすれば，不法汲取の削減が可能であると示唆された。

以上のように本論文は，不十分な廃棄物の管理が住民の生活環境・健康生活を劣悪としている途上国都市部において，その要因解明のためのマテリアルフローの構築とその適用を示し，その具体的対策としてし尿汚泥の汲取への対応策を実証的に検証することで，今後の途上国環境衛生改善に大きく貢献し，学術上，実務上寄与するところが多い。よって，本論文は博士（工学）の学位論文として価値あるものと認める。また，令和元年 8 月 21 日，論文内容とそれに関連した事項について試問を行い，申請者が博士後期課程学位取得基準を満たしていることを確認し，合格と認めた。

なお、本論文は、京都大学学位規程第１４条第２項に該当するものと判断し、公表に際しては、該論文の全文に代えてその内容を要約したものとすることを認める。